

# Single Spin Asymmetries at RHIC<sup>1</sup>

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## Abstract

One purpose of this meeting is to assess the physics potential of HERA-N Stage I. To develop a reasonable perspective, it is useful to look at other spin experiments. For completeness, this report discusses some of the single spin physics that has appeared in studies relating to the Relativistic Heavy Ion Collider (RHIC).

## 1 Introduction

One purpose of this meeting is to assess the physics potential of HERA-N Stage-I (HNSI). To develop a reasonable perspective, it is useful to look at other spin experiments. For completeness, this report discusses some of the single spin physics that has appeared in studies relating to the Relativistic Heavy Ion Collider (RHIC).

Recall[1], in HNSI an unpolarized proton beam of 820 GeV would collide with a polarized nuclear target enabling us to study proton-proton and proton-neutron asymmetries at a center of mass energy near  $\sqrt{S} \approx 40$  GeV. The luminosities anticipated range is from  $8 - 240 \text{ pb}^{-1}$ . For understanding what physics can be expected from this single spin experiment, we can ask about the relevance past studies performed for RHIC have with regard to HNSI.

It is important to note that there are significant differences between HNSI and the early runs at RHIC. The spin program at RHIC[2, 3] involves collisions between two polarized proton beams. The energy range for the early runs are expected to be from  $200 - 500$  GeV, though in the end the range may run from

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50 – 500 GeV. The integrated luminosity expected is about  $800\text{pb}^{-1}$  ( $320\text{pb}^{-1}$ ) at  $\sqrt{S} = 500\text{ GeV}$  (50 GeV) with beam polarizations roughly around 70%.

This disparity between the two machines leads to a tremendous difference in the focus between the RHIC project and HSNI. In the first place, both beam spins will be under control at RHIC, so their focus is naturally on double spin asymmetries. Single spin asymmetries from RHIC can be obtained for free, however, simply by combining cross sections with complementary spin combinations. In the second place, the RHIC energies are high enough to study  $W^\pm$  and  $Z^0$  boson physics. Parity violation is manifest in the weak interactions and may even be used as a tool.

In the original RHIC spin proposal little is said about single spin asymmetries[2]. One item refers to the potential of measuring the longitudinal single spin asymmetry  $A_L$  and the transverse spin asymmetry  $A_N$  in elastic scattering at small  $|t|$ . What is also needed is a study of the energy dependence of the forward hadron reactions in the total cross section,

$$\sigma^{tot} = \frac{2\pi}{k} \text{Im}[\phi_1(0) + \phi_3(0)], \quad (1)$$

$$\Delta\sigma_L = \frac{4\pi}{k} \text{Im}[\phi_1(0) - \phi_3(0)], \quad (2)$$

$$\Delta\sigma_T = -\frac{4\pi}{k} \text{Im}[\phi_2(0)], \quad (3)$$

where  $\phi_{1,2,3}$  are the  $s$ -channel helicity amplitudes.

Also discussed is how measuring  $A_N$  (the single spin transverse asymmetry) in

$$p^\uparrow p \rightarrow \gamma + X \quad \text{and} \quad p^\uparrow p \rightarrow \pi^0 + X$$

will probe the twist-3 structure of the hadron. Since higher twists should not contribute at high energies, one could also test the prediction of perturbative QCD for a vanishing one-spin transverse asymmetry ( $A_N = 0$ ) in high- $P_T$  inclusive production. The study of the  $P_T$  dependence of one-spin asymmetries might reveal the transition from the nonperturbative phase of QCD ( $A_N \neq 0$ ) to the perturbative part ( $A_N = 0$ ). Moreover, this experiment is clean compared to longitudinal spin and double spin experiments since it doesn't have leading twist variations tangled together with the effects due to nonleading twist. Such data also will provide information on the correlations between the quarks and gluons inside the proton, which can be used to constrain the various nucleon models.

In QCD, where parity is conserved, the single spin longitudinal asymmetry ( $A_L$ ) is zero at the tree level. In contradistinction to this, the weak interactions typically yield  $A_L \neq 0$ . Looking at the factorization of the cross section for  $A_L$ ,

$$A_L \propto \sum_{\text{partons } a,b} \int dx_1 dx_2 \Delta f_{a/A}(x_1, Q) f_{b/B}(x_2, Q) \hat{a} d\sigma, \quad (4)$$

it is apparent that the nonzero asymmetry of the hard interaction,  $\hat{a}$ , permits a probe of the helicity distribution  $\Delta f(x, Q)$ . In Fig. 1, it is depicted how the production of gauge bosons will probe the helicity distributions for sea quarks through  $A_L$ .

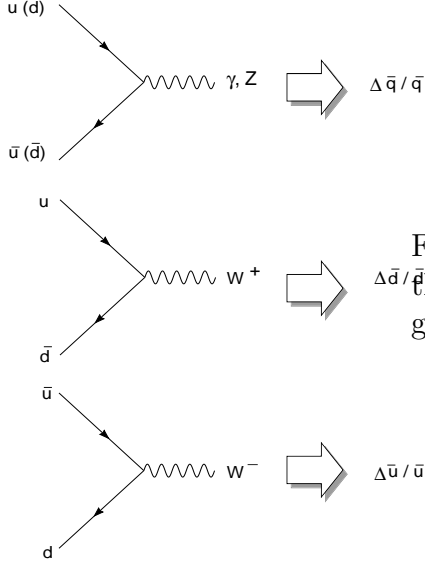


Fig. 1: Different flavors for the helicity densities of the sea quarks are probed depending upon which gauge boson is produced.

The single spin asymmetries have been computed for the Drell-Yan process and for gauge boson production. In particular, Leader and Sridhar have computed  $A_L$  for the Drell-Yan process including the interference effects between the photon and  $Z$  boson at  $\sqrt{S} = 500$  GeV. As would be expected, the parity violating asymmetry is most sensitive to variations in the helicity densities as the energy for the subprocess approaches the  $Z$  boson mass. Variations on the order of 20% may appear.

Bourrely and Soffer have computed the asymmetries for electroweak boson production at  $\sqrt{S} = 500$  GeV[4]. They find the single spin asymmetry spanning ranges as large as 60% across the boson's rapidity. The largest variation with a change in polarized parton distributions appears for the  $W^+$  boson. This should provide a decent probe of the  $\Delta \bar{d}$  distribution function. In fact, studies by the STAR and PHENIX Collaborations indicate that with the tens of thousands of  $W$  boson events they can collect, the statistical bound on how well we can determine  $\Delta \bar{u}/\bar{u}$  and  $\Delta \bar{d}/\bar{d}$  is to within 3%[5].

Jet production, even though dominated by QCD processes, may carry a parity violating behavior due to the electroweak production mechanisms and their interference with QCD processes[6]. This parity violation can appear in  $A_L$ . Without cuts, Ref. [6] demonstrates asymmetries around the percent level for  $pp$  and  $p\bar{p}$  collisions ranging from  $\sqrt{s} = 250 - 850$  GeV. With high luminosities, the RHIC should be able to observe some variation.

Though parity conservation yields  $A_L = 0$  for single particle inclusive processes at the tree level, it is possible to get nonzero asymmetries by observing

more than one particle in the final state. In particular, Pire and Ralston[7] and Carlitz and Willey[8] demonstrate nonzero asymmetries that appear at the one loop level in the production of dilepton pairs. These dileptons may be produced by a Drell-Yan mechanism or through decays *e.g.*, of  $J/\psi$ .

The longitudinal asymmetry arises from the vector product  $\mathbf{s} \cdot (\mathbf{q}^+ \times \mathbf{q}^-)$ , which is odd under time reversal. ( $\mathbf{s}$  is the spin vector,  $\mathbf{q}^+$  is the  $\mu^+$  momentum and  $\mathbf{q}^-$  is the  $\mu^-$  momentum.) Consequently, imaginary parts of the one loop amplitude in the lepton pair production provide for the nonzero asymmetry. The parton level asymmetry corresponding to  $A_L$  is computed by Carlitz and Willey and found to 10 – 30% for  $\tau = -t/(\mathbf{q}^+ + \mathbf{q}^-)^2 < 10$ . Ideally, by using different kinematics, it should be possible to focus on subprocesses with either the quarks or gluons in the initial state. Through this asymmetry, it becomes possible to collect information on the helicity distributions. These ideas can be applied to other processes also, like open heavy quark production, dijet production and  $\gamma$ +jet production. At RHIC, however, such data cannot compete with the probe into the parton distribution functions that the double spin asymmetries can provide.

Other opportunities exist. For example, in the forward scattering region the outgoing quark is expected to maintain the helicity of its original state. Analyzing the polarized fragmentation of the resulting particle jet can provide information on the the chiral structure of QCD and also yield a useful tool for further polarization experiments[9].

It was not the intent of this talk to enter into a description of the theoretical details regarding single spin asymmetries. For further discussion on theoretical motivations for studying single spin physics at hadron-hadron colliders, I direct the reader to the *Review of the RHIC Spin Physics Program*[5] and to an excellent review written by S.M. Troshin and A. Krisch in the *Acceleration of Polarized Protons to 120 GeV and 1 TeV at Fermilab* for the SPIN Collaboration. Though the discussion in the latter document is directed toward the Fermilab facility, many of the ideas apply equally well to the high energy collisions at RHIC.

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